Engineering Case Library

ECL 200A

150 TON PIPE: EASIER TO MAKE THAN TO MOVE

This pipe is fabricated standing on end. Before it could be laid in place, some method of tipping it over had to be devised. Pipe size and weight added complexity to what otherwise appeared to be a relatively easy problem.

The assistance of Mr. Valdek Aviko, Project Engineer at Ameron, is gratefully acknowledged.

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In order to utilize his natural assets, man has often had to transport resources from locations of abundance to those of need. The magnitude of this redistribution is dramatically demonstrated in the California Water Project, transporting excess Northern California water to fill the needs of expanding Southern California agriculture and population. In both size and technical innovation, the project is a great engineering feat.

Lifting the water over the rugged terrain in Southern California requires the use of several siphons. The desire for long life with little maintenance dictated concrete pipe for these siphons, and the ability to withstand pressures of up to 300 feet of water head made prestressing desirable. These factors, combined with the volume of water needed, led to the world's largest prestressed concrete pipe then in existence. The pipe discussed here was used in that part of the project which carries water from the Castaic Dam to Los Angeles. This section was completed in October 1970.

Ameron (then American Pipe and Construction Company) contracted to supply this pipe at the job site in Valencia, California. Each section of the pipe, with an inside diameter of 201 inches (16 ft., 9 in.) and a 20 ft. length, weighs 150 tons. The initial concrete core (1.5 in. thickness) is surrounded by a 17 foot diameter steel cylinder which is itself then encased in concrete, giving an 18 inch wall thickness. This is then wrapped with two courses of prestressing wire drawn to precise tensions of up to 170,000 psi. Concrete mortar covers the wire making a 20 inch total wall thickness. Each of these pipe sections costs approximately $9,000. Construction of pipe this size had never before been attempted and required the design of several unique machines.

Except for the fabrication of the steel cylinder, all of the steps in the pipe construction are accomplished with the pipe sections standing on end. Moving these sections through each of the assembly points required a machine capable of lifting and carrying up to 150 tons. The Liftmobile, shown in Exhibit A-1 was Ameron's answer. This mobile gantry, nearly 50 ft. high, was designed for a maximum load of 246 tons. Besides its transport role, it was also to lay the finished pipe on its side so that it could then be handled by the Pipemobile. (The Pipemobile, patented by Ameron, is described in Exhibit A-2.) In order to insure that the pipe sections would fit properly together, the section ends must not be damaged during any of this processing.

The Liftmobile is equipped with a series of blocks and tackle suspended from its arch. Hooks on the blocks support a lift ring which actually lifts the pipe sections. (Figure 1)

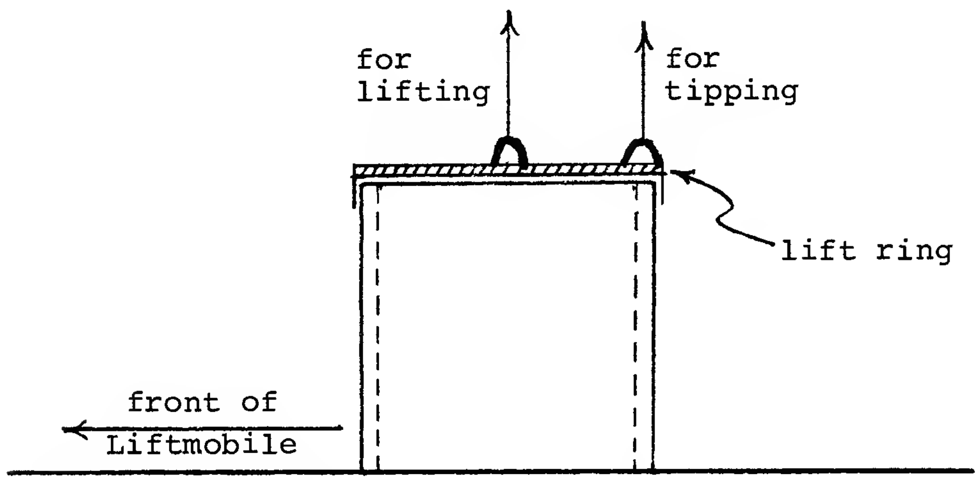

Figure 1

To tip the pipe on its side, the Liftmobile operator simply places the pipe on the ground, moves the lifting hooks from their attachments at the center of the lift ring to those provided on the circumference, and begins to lift. As the pipe tilts, the operator moves the vehicle forward, attempting to keep the lifting lines always at some angle from the vertical so as to be pulling as well as lifting. This process is continued until the pipe is on its side. The Pipemobile (Exhibit A-2) then takes over and moves the pipe to its exact final location.

Problems soon arose with the tipping operation of the Liftmobile. The lift ring, quite adequate for its lifting function because its entire circumference is uniformly loaded, was found to be inadequate for tipping unless the operation was accomplished with a high degree of precision. One of the first completed pipe sections was dropped during this tipping operation.

Valdek Aviko, Project Engineer, at Ameron's Corporate Equipment Engineering Division, South Gate, California, was called upon to analyze this failure. He determined that any attempt to place more than half of the pipe load on the lift ring, eccentrically supported in the tipping mode, resulted in the lift ring snapping loose from the pipe. This excess load

resulted from failure to move the Liftmobile forward sufficiently while the lift lines were being raised. As the lift lines became vertical and attempted to raise the pipe off the ground, the lift ring became overloaded. Mr. Aviko suggested that a procedure be adopted whereby the operator could insure that the lift lines were never vertical. An angle of 10 degrees was chosen as a convenient minimum. This solution was adopted.

Several weeks later, Mr. Aviko again received a call from Valencia explaining that once again a section of pipe had been dropped. (This time the swinging lift ring had caused damage to the Liftmobile itself.) The source of this new problem was the weather. Continued rain had softened the ground sufficiently for the tipping pipe to embed itself in the mud. At approximately 45 degrees the pipe was supported by such a mud build-up that the Liftmobile operator could no longer apply sufficient lateral force to tip it. His solution was to try to pull the pipe out by winching in the lift lines which had again overloaded the lift ring.

In addition to these failures, the Valencia engineers complained that this tipping method was damaging that section of the pipe rim upon which the tipping pipe pivoted. The site was now also producing two pipes of smaller diameter (156 inches and 150 inches) requiring the lift ring to be changed frequently during each day's operation. This time consuming function, the increased production volume (8 pipes per day maximum as opposed to 4 of the large pipes per day), the possibility of causing human injury, and the cost, in both machine repairs and damaged pipe, of continued accidents led the on-site engineers to request a new device to relieve the Liftmobile of its tipping function.

The 150 Ton Tipping Machine was designed for this purpose (Exhibit A-3). Mr. Aviko got the idea for this design from observing similar machines which tipped railroad cars loaded with coal so they could be emptied rapidly. Costs and development time had to be sufficiently low to meet production schedules and profit expectations. $40,000 was budgeted for the project based on the engineer's estimates, and three months were allotted for construction and installation of the machine. These projections were met and the 150 Ton Tipping Machine began operation at Valencia. (This machine cost only as much as 4 or 5 damaged pipe sections.)

Each pipe section is placed on the tipping machine by the Liftmobile. Rotating the pipe is accomplished in two steps. The weight of the pipe rotates the machine through the first 45 degrees. The operator uses the brake on the winch drum to regulate this rotation. The winch (see Exhibit A-4) is then used to pull the tipping machine through the remainder of its arc.

The magnitude of the brake force and the winch force required to hold the tipping machine at any angle dictate the size of the brake, the power of the winch motor and the strength of the cable to be used on the machine. The magnitude of these forces depend on the size of the pipe to be tipped and its location on the machine. Mr. Aviko originally designed the machine specifically for the 201 inch, 150 ton pipe. He arranged the pipe supports so that the winch force required to rotate the pipe would actually be less than that needed to rotate the empty machine. In addition the pipe wall support (see Exhibit A-5) was located so that the large pipe, once it was tipped, could be rolled from the machine without the use of inclined ramps. The decision to use the machine to tip smaller pipes, although they weighed less, required modification of the pipe end supports and increased winch and brake force due to their offset center of gravity.

In rolling the pipe off the machine, several load reversals were encountered. The machine is at first loaded, then empty, then loaded with the weight of the tractor, and finally empty again. Since there are no brakes on the supporting trunions, quite a bit of rocking occurred in the machine decking during this operation. A field expedient method of pinning the rotated frame to the concrete trench resulted in breaking several sections of the trench which could not withstand the forces applied. Again Mr. Aviko was called, and again the solution was a modification of operating procedure rather than a change for the machine itself. By tightening the winch cables the machine can be locked firmly into the horizontal position regardless of the load reversals it might experience.

With these modifications the tipping machine was used successfully until its role in the Valencia project was completed in April 1970. It is now in use at "Four Corners," New Mexico on a similar project.

STUDENT QUESTIONS:

1. Both the 201 inch pipe and the 150 inch pipe must roll from the tipping machine without the use of inclined ramps. This requirement fixes the location of the pipe wall support. (See Exhibit A-5). The pipe end support, however, may be raised to adjust the height of the 150 inch pipe.

a. For what position does the empty machine require the greatest force in the winch cable? Is this force exerted by the brake or the winch motor? What is the magnitude of the force?
b. Answer the same questions as in part "a" for the machine loaded with the 201" pipe.
c. If the 150 inch pipe is to be rotated on the tip machine without changing any supports, what brake force and winch force would be required? Which of these forces can be reduced? Adjust the height of the pipe end supports so that the winch which rotates the empty machine is large enough to rotate the 150 inch pipe.

Dimensions:

Pipe A: ID-201 inches; OD-241 inches; length-20 ft.; weight-300,000 pounds.

Pipe B: ID-150 inches; OD-178 inches; length-16 ft.; weight-125,000 pounds.

Tip Machine: (See Exhibit A-5)
1) Rocker: weight - 18,000 pounds; radius - 17 feet outside, 15 feet inside;
2) pipe wall support - 8,000 pounds;
3) pipe end supports - 2,000 pounds each;
4) 4,000 pound counter-balance is collocated with left pipe end support.

2. Draw a free body diagram of the Liftmobile just as it starts to tip the 201", 150 ton pipe. Assume lift lines at a 10° angle with the vertical. The Liftmobile weighs 96 tons. This weight is distributed as follows:

forward section - 20 tons
lift ring - 10 tons
arch - 36 tons
horizontal frame - 30 tons

Total length is 55 feet and the rear wheel diameter is 10 feet. Compute the reaction force on the front and rear wheels.

3. Describe several possible devices which could replace the Liftmobile in its tipping function or which could assist the Liftmobile in making its tipping function less hazardous and less time consuming. Discuss the advantages of each proposed design.

LIFTMOBILE

EXHIBIT A-1
page 1 of 2

LIFTMOBILE

EXHIBIT A-1
page 2 of 2

PIPEMOBILE

The 140 ton Pipemobile was designed and built specifically for use with the 201 inch pipe. This patented machine was designed to literally crawl through a pipe section, lift it, carry it over varied terrain (grades to 35 percent), and put it in place ready to be sealed to the other pipe sections. The Pipemobile operator places the 10 foot diameter fifth wheel inside the pipe section and then lowers it. This raises the two rear wheels until they too are high enough to enter the pipe. After traversing the pipe section the two rear wheels are again lowered. Hydraulic pistons then raise the frame of the Pipemobile to lift the pipe to its transport position.

EXHIBIT A-2

EXHIBIT A-3
150 Ton Tipping Machine

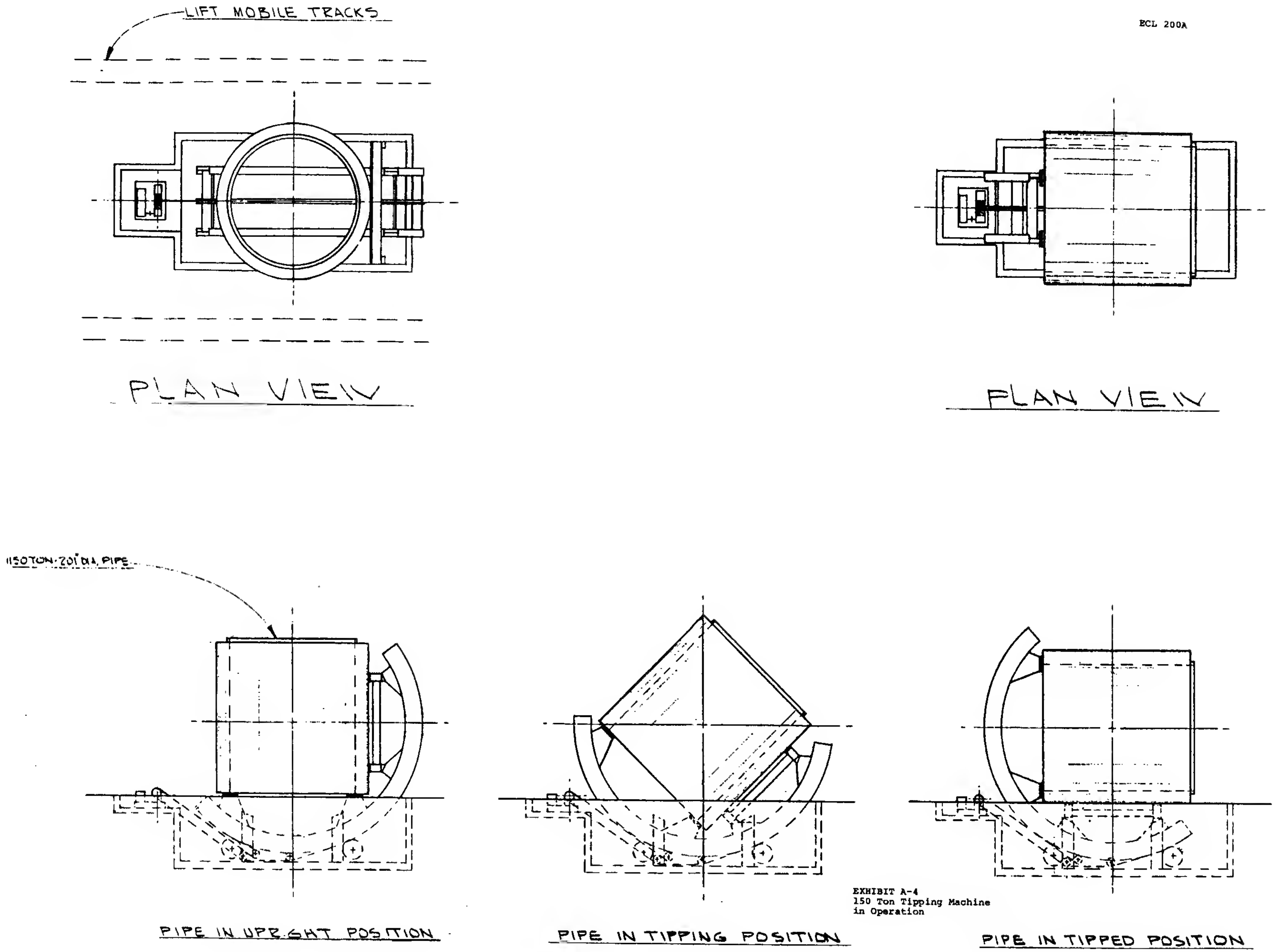

EXHIBIT A-4
150 Ton Tipping Machine
in Operation

ENGINEERING CASE LIBRARY

ECL 200B

150 TON PIPE

Part B: TIP MACHINE PROPOSALS

The design for the 150 ton Tipping Machine evolved from several less complex proposals. This section contains a discussion of three of Mr. Aviko's preliminary proposals. The advantages and disadvantages of the machine that was eventually selected are also contained in this section.

Initially it was not known whether pipe could be rolled once it was laid on its side. Fear that insufficient curing time had elapsed, that pipe would deform from its own weight, and that damage would be done to the prestressing wire all proved to be unfounded. Also, the fact that all tipping would be done in one place was considered to be neither an advantage nor a disadvantage over tipping the pipe sections where they were cured.

1. Rocker (Exhibit B-1)

   Advantages:

   a. Used with center lift pin of the lift ring -- no time loss in changing lift line attachments.

   b. Simple construction -- low cost.

   c. Easily transported to new job sites.

   d. Less chance for operator error during tipping since winch would be operated in only one direction.

   e. Auxiliary tractor to roll pipe off unnecessary.

   Disadvantages:

   a. Possible pipe damage when rocker disconnects and rocks back.

   b. Damage to pipe at pivot point.

   c. Operation still subject to weather and ground conditions.

   d. Must use Liftmobile time through entire tipping process -- this is critical.

   e. Tractor needed to move rocker.

2. Winched Rocker (Exhibit B-2)

   Advantages:

   a. Items a, b, and c from the Rocker.

   b. Liftmobile not required during tipping.

   c. More positive, continuous control compared to free moving rocker.

Disadvantages:
a. Safety -- would work well on solid ground but unstable in mud or uneven terrain. Would need to construct concrete platform to insure stable operation.

b. Motor required for winch.

c. Auxiliary tractor needed for moving device and rolling pipe off.

d. Pipe rolled down ramp rather than being at ground level.

e. Possible damage to pipe end in rolling from platform.

3. Trenched Rocker (Exhibit B-3)

Advantages:
a. Safety -- restrained movement gives less chance for operator error.

b. Simple construction -- low cost.

c. Pipe rolls off at ground level.

d. Liftmobile not required during tipping.

e. Concrete trench gives smooth, stable base unaffected by weather.

Disadvantages:
a. Motor required for winch.

b. Tractor needed to roll pipe off.

c. Fixed in place -- pipe must be moved to it.

d. Device would tend to slip in trench instead of just rocking

e. Harder to adapt to different sized pipe.

4. 150 Ton Tipping Machine

Advantages:
a. Liftmobile not required during tipping operation.

b. Pipe at ground level for rolling off machine.

c. Motion is rotation only -- added safety over translational trenched rocker.

d. Simplified winch system over either Winched or Trenched Rocker.

e. Concrete trench makes operation unaffected by weather.

f. No damage to pipe ends during roll off due to lateral push from hydraulic pistons.

Disadvantages:

a. Structurally the most complex -- most costly.

b. Fixed in place -- pipe must be moved to it; hardest to move to new job site.

c. Winch required -- but smaller than that for Winched Rocker.

d. Auxiliary tractor required to roll pipe off.

e. Only braking force is that provided by winch cable held tight at both ends. This was later partially corrected by using a chain rather than a cable on the winch.

STUDENT QUESTIONS:

1. Exhibit B-2 shows the Winched Rocker in three positions as it tips a 201 inch pipe section. (Note scale on drawing.) Neglect the weight of the machine. Assume that the moment of the pipe about the point of contact is constant. In which position will the maximum downward force be applied to the small wheel shown? In which position will the maximum cable pull occur? Calculate these quantities. How could the maximum cable pull be reduced?

2. Mr. Aviko believed that the Trenched Rocker would have a tendency to slip on its steel tracks as well as to roll. What coefficient of friction is required to keep the Trenched Rocker from slipping rather than rolling? Were Mr. Aviko's fears justified? See Exhibit B-3. (Note scale on drawing.)

AMERICAN PIPE AND CONSTRUCTION CO.
CORPORATE PLANT ENGINEERING

ECL 200B

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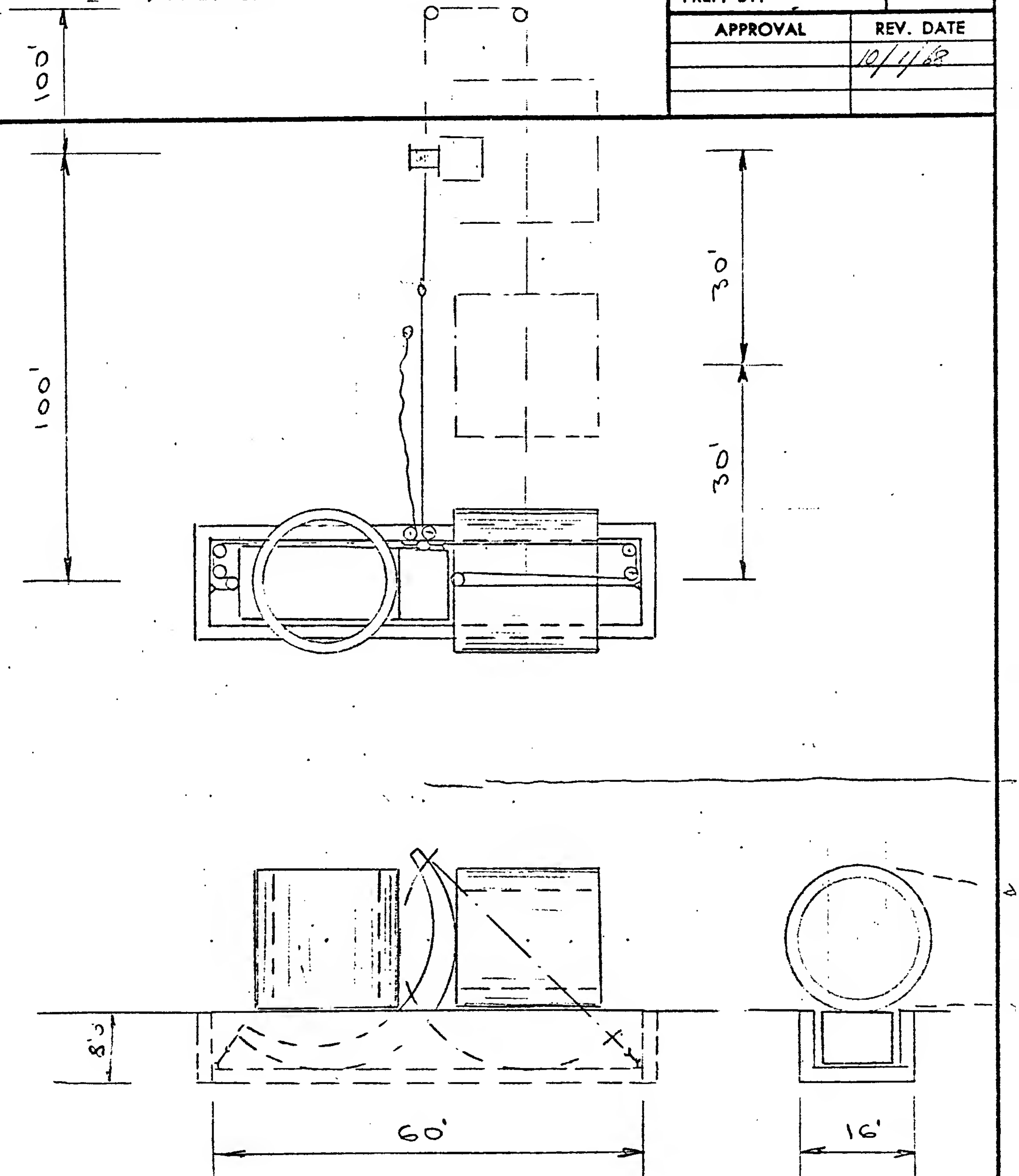
Trenched Rocker



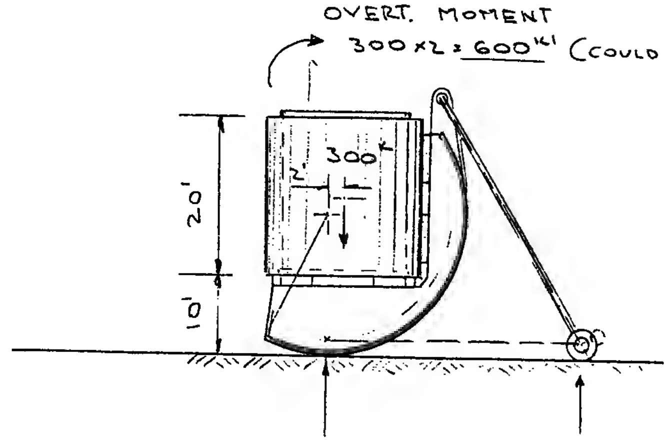
1 inch = 20 feet

EXHIBIT B-3
Trenched Rocker

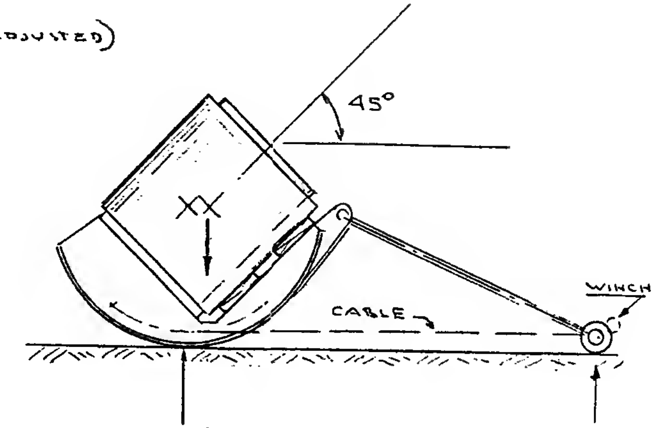
CPE 1

PROPOSED 150-TON PIPE TIPPING STAND

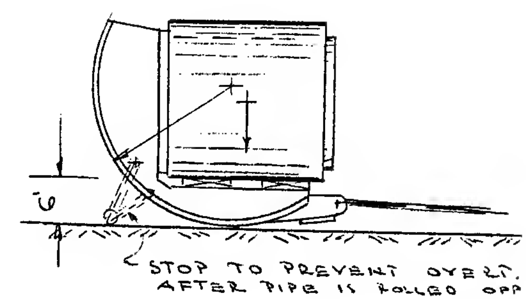
Winched Rocker



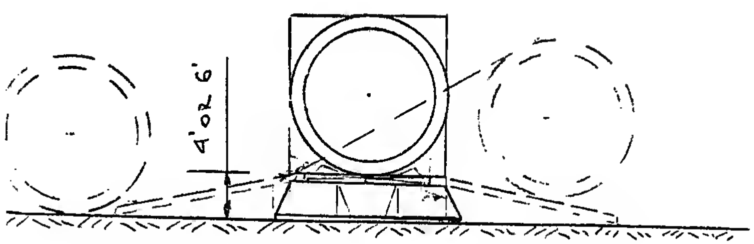
① POSITION PIPE ON STAND



② TIPPING IN PROCESS @ 45°

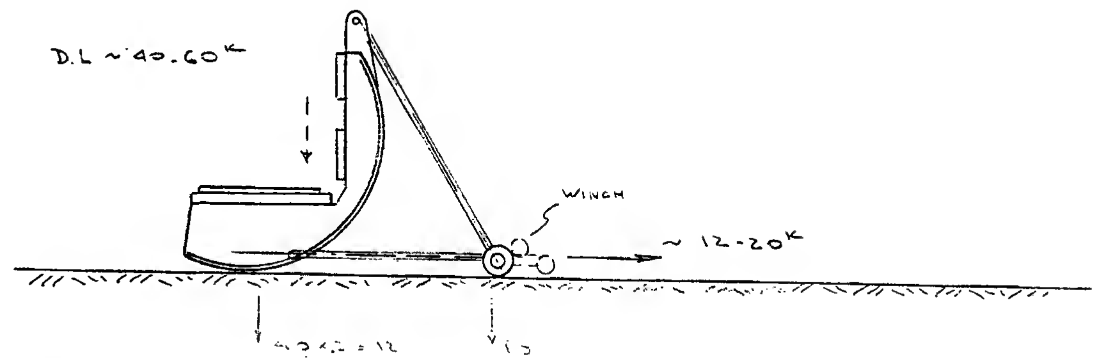


③ TIPPING COMPLETED



UNLOAD PIPE TO EITHER SIDE

THEN MOVE TIPPING STAND TO NEW LOCATION



TIPPING STAND READY TO BE MOVED TO NEW LOCATION FOR TIPPING

EXHIBIT B-2
Winched Rocker

ECL 200B

PROPOSAL TO TIP PIPE WITH CENTER PIN USING ROCKER

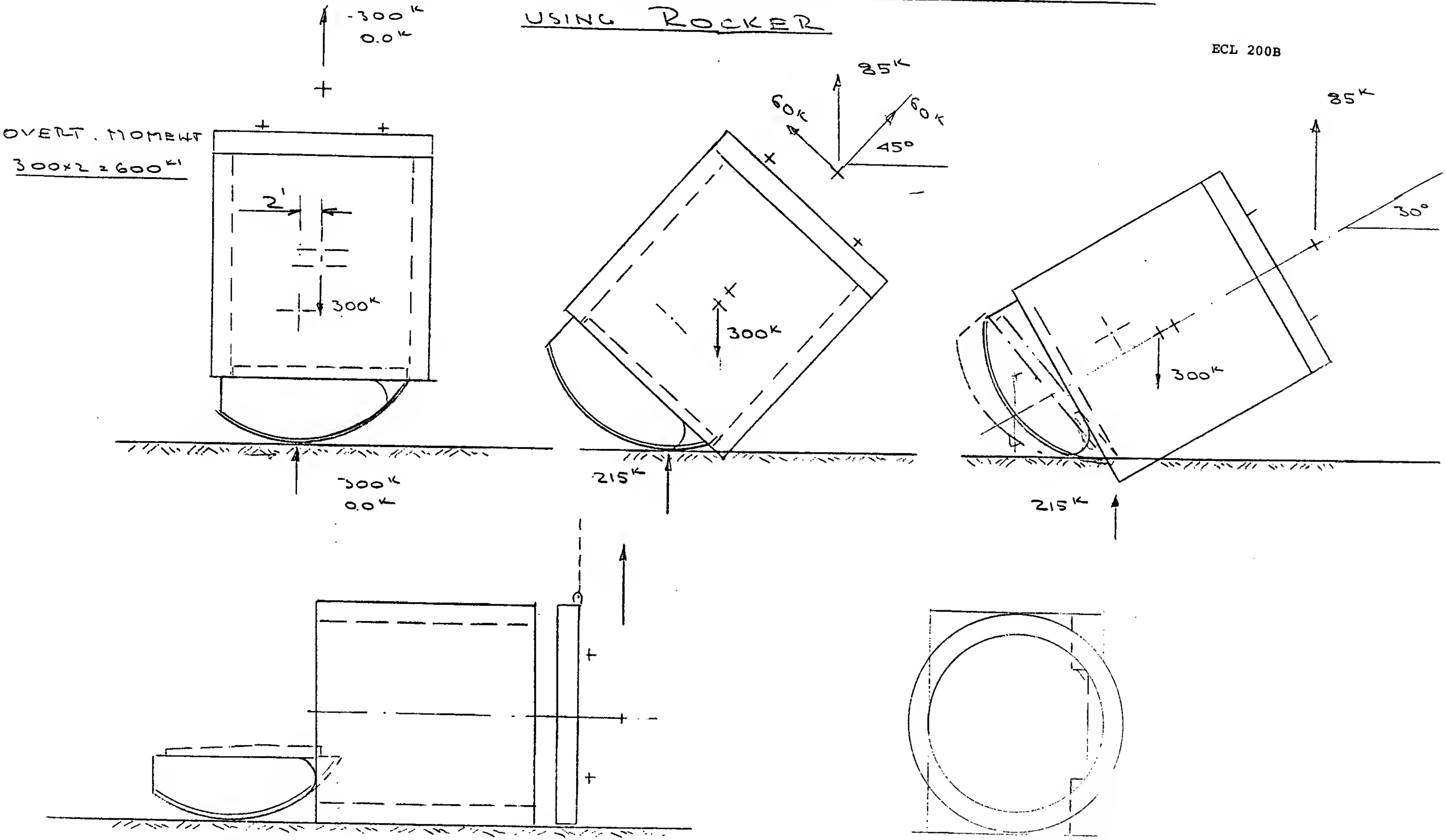


EXHIBIT B-1
Rocker

INSTRUCTOR'S NOTES

Part B

1. This problem challenges the students' ability to properly analyze a complex structure using a free body diagram. The fact that the wheel is on a pivoted arm does not affect the calculation of the reaction force. All lengths used here are measured directly from Mr. Aviko's drawing.

a. The maximum downward force on the small wheel occurs in position 1. Summing moments about C:

$$\Sigma M_C = 0 = (300\text{K lb})\ (2\text{ ft}) - (R\text{ lb})\ (32.9\text{ ft})$$

$$R = \underline{18{,}250\text{ lb}}$$

b. Maximum cable pull is in position 3.

Reaction on the wheel:

$$\Sigma M_C = 0 = (300\text{K lb})\ (2\text{ ft}) - (R\text{ lb})\ (47.45\text{ ft})$$

$$R = \underline{12{,}650\text{ lb}}$$

In order to prevent the 35.7 foot arm attached to the small wheel from rotating about pivot point, P, the moment caused by the cable pull, C, must balance that caused by the reaction force on the wheel.

$$\Sigma M_P = 0 = C(3.5\text{ ft} - 2\text{ ft}) - (12.65\text{K lb})(35.7\text{ ft})$$

$$C = \underline{301{,}000\text{ lb}}$$

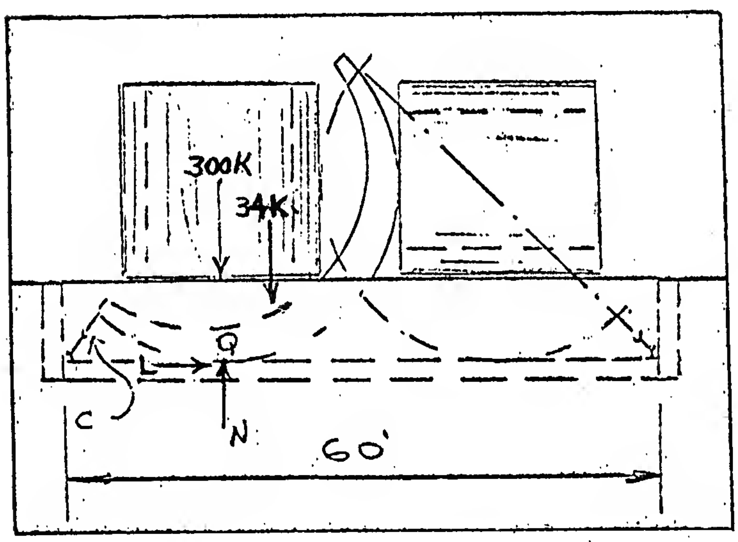
It is not clear whether the designer actually made this calculation, but the requirement for such a high cable strength would definitely influence the rejection of this proposal.

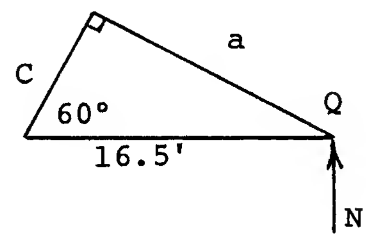
Cable pull can be reduced by increasing its moment arm about the pivot point when the machine is in the tipped position. This requires either lowering the line of action of the cable or raising the pivot point itself.

NOTE: Instructor may wish to have students include the effects of machine weight or the longer moment arm for the pipe ($2\sqrt{2}$ ft.) in position 2. Machine weight is estimated 40,000 lbs with 25,000 lbs located in the base, and 15,000 lbs located in the upright position.

2. This question requires the student to apply his understanding of friction. The structural design of this machine is taken to be nearly the same as the 150 ton tipping machine. Center of gravity calculations from Part A for the empty machine are assumed correct. One important difference shown in the drawing of the Trenched Rocker is that the pipe center is collocated with the center of rotation of the machine. The pipe, therefore, adds only normal force to the problem, and slipping is most likely to occur while rotating the empty machine.

The maximum cable pull, C, and therefore the maximum lateral force occurs in the untipped position shown. In this position the weight of the machine is acting on its maximum moment arm, and the moment arm, a, for the cable pull has its smallest value. The cable angle is 60° in this position.





$$a = (16.5\text{ ft})(\sin 60°)$$
$$= \underline{14.3\text{ ft}}$$

Summing moments about point of contact, Q:

$$0 = (34\text{K lbs})(5.34\text{ ft})^{*} - C(14.3\text{ ft})$$

*From Problem 1a, Part A

$C = 12{,}700$ lbs

$C_x = 6{,}350$ lbs $\qquad C_y = 11{,}000$ lbs

Let μ_s be the friction coefficient required to prevent slipping of the empty machine.

$$\mu_s = \frac{L}{N} \qquad \text{where } L = C_x$$

$$= \frac{6.35K}{45K} \qquad N = 34K + C_Y$$

$$\mu_s = .141$$

Friction coefficient for dry steel on dry steel ranges from .3 to .5. For oil lubricated contact the coefficient can be as low as .1. We can only speculate how the coefficient would vary on a rainy day or with normal construction site oil and gasoline spillage.